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U.S. DEPARTMENT OF AGRICULTURE

CIRCULAR No. 364 NOVEMBER 1935
UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

CYANIDE FUMIGATION OF MUSHROOM HOUSES

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INTRODUCTION

It is the general practice among mushroom growers to fumigate the houses when the maximum temperature, or " peak heat ", has been reached in the freshly filled houses, on the theory that the insects not killed by the excessive heat of the compost will be driven to the surface where they will be exposed to the fumigants. During the period of secondary fermentation of the compost in mushroom beds, which is customarily referred to as the " heat ", the air temperature of a mushroom house may reach from 120° to 140° F. at the ceiling, from 100° to 120° at the level of the bottom beds, and from 90° to 108° at the floor level, the compost in the beds being even hotter; and fans are used in an effort to equalize the temperature. The relative humidity is usually around 90 percent at this time. The compost in the beds, the false ceiling, the walls, and the floor are very moist.

Under such conditions of heat and moisture, hydrocyanic acid gas is absorbed from the air with great rapidity. This absorption, however, has little or no harmful acidifying effect on the surface of the compost. Furthermore, the average mushroom house is so constructed that it is difficult, if not impossible, to seal it tightly, so leakage is more or less unavoidable.

Investigations were therefore undertaken in the mushroom-growing center about Kennett Square, Pa., and at Arlington Experiment Farm, Va., for the purpose of comparing the concentrations of hydrocyanic acid gas obtained with the three most common methods of generation, and to determine its effectiveness, under conditions encountered in the houses at peak heat, against the insects and mites that attack mushrooms.

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Since it was not usually desirable to place insects in the houses during fumigation, analyses were made to determine the concentrations of gas obtained in the tests. The concentrations thus determined were afterwards reproduced in a fumigation chamber and the effect upon the insects and mites determined.

MUSHROOM HOUSE FUMIGATION

MATERIALS AND METHODS

The three sources of hydrocyanic acid, the fumigating gas, are calcium cyanide, which is usually in granular form and from which the gas is liberated when moisture is taken up from the air; sodium cyanide, which is dropped into an earthen jar of dilute sulphuric acid for the formation of the gas; and liquid hydrocyanic acid, which is a compressed form of the gas furnished in heavy metal cylinders.

In order to attain a concentration high enough to be effective, the gas must be generated as rapidly as possible. The fans need not be removed from the house during fumigation with hydrocyanic acid gas, and their operation assists materially in obtaining a rapid and uniform distribution of the gas.

FUMIGATION WITH CALCIUM CYANIDE

Calcium cyanide is used at from three-fourths to 1 pound per 1,000 cubic feet of air space, the heavier dosage being the more common. The central alleyway of the house is lightly sprinkled if too dry, or mopped drier if too wet, according to the judgment of the individual. The cyanide is weighed out, placed in a pail or other receptacle, and scattered as evenly as possible down the center alleyway of the house, the operator walking backward toward an open door at the end of the house as he distributes the material. In the case of a double house, two men distribute the cyanide, starting at the far end of the central alleyway of each house at the same time and timing their operations so as to arrive at the doors of their respective houses simultaneously.

FUMIGATION WITH SODIUM CYANIDE

For fumigation by the " pot " or " hot gas " method, sodium cyanide is used at the rate of one-half pound per 1,000 cubic feet of air space, this dosage being approximately equal to 1 pound of calcium cyanide per 1,000 cubic feet in the volume of hydrocyanic acid gas produced. For a standard-size house (16,000 cubic feet), four glazed earthenware crocks, each capable of holding a total of 3 gallons, were used to generate the gas. The common formula of 1½ fluid ounces of acid, 2 ounces of water, and 1 ounce of sodium cyanide was used. The 2 pounds of cyanide to go into each generator was weighed out (or, if in egg or ball form of ½ or 1 ounce, counted out) and placed in a heavy paper bag. Two quarts of water was put into each generator, and the generators set at equal distances apart down the central alleyway of the house. One and one-half quarts of a good grade of commercial sulphuric acid (66° Baumé) was then measured out for each generator, and placed in a jar beside the generator. The bags of cyanide having been taken to the rear or far end of the house and left there, out of any standing water, the operator walked up the length of the central alleyway, carefully pouring the acid into the generators as he went. Upon reaching the rear of the house he took up the bags of cyanide and walked toward the front of the house where the door was held open, dropping a bag of cyanide into each generator as he passed it. In the case of a double house, two men would be required, as for fumigating with calcium cyanide.

FUMIGATION WITH LIQUID HYDROCYANIC ACID

Liquid hydrocyanic acid requires special apparatus which consists of a cylinder of the liquid, a pump by means of which a pressure may be built in the cylinder, a pressure gage to determine the pressure, mounted upon a " delivery cross " which enables the operator to regulate the flow of gas and to blow the line clear, a 1/8- or 1/4-inch delivery line equipped with spray nozzles, and a platform scales upon which to weigh the quantity of gas used. In the present experiments, a 1/4-inch delivery line was run along the central alleyway, on or suspended from the supports of the center walk, the nozzles directed downward. The dosage, for comparative purposes, was one-fourth pound per 1,000 cubic feet of air space, this being equivalent to the volume of gas capable of being released by 1 pound of calcium cyanide or one-half pound of sodium cyanide.

After fumigation by any of these methods the house was closed tightly and left so for several hours, or until analysis showed that the gas was nearly gone from the house. Analyses were made at intervals to determine the concentration of gas. The glass tubing through which samples were drawn for analysis was led into the house through holes near the door, the intake of each being about 12 feet from the end of the house.

The time intervals of sampling were calculated from the minute that actual fumigation operations commenced, that is, when the operator dropped the first bag of sodium cyanide, or the first handful of calcium cyanide, or turned the release valve on the delivery cross of the cylinder of liquid hydrocyanic acid.

DISTRIBUTION OF THE GAS

The temperature in the upper one-half or two-thirds of the mushroom house at peak heat is usually high enough either to kill all pests or drive them from the manure. In most cases when so driven out, they fall to the floor and may survive there to reinfest the upper beds. For this reason it is important that the lower third of the house receive a good fumigation. Hydrocyanic acid gas, being lighter than air, ordinarily rises to the top of the house and remains there, the floor receiving very little benefit from it. This is especially true of the hot gas from the acid generation. Fortunately, the fans may be left running in the house during cyanide fumigation, making possible a fairly uniform distribution of gas. For distribution of temperature the fans, 2 to the standard house of 65 feet, are placed on the floor in the central alleyway with the air current directed upward toward the ceiling of the house. During fumigation, however, it is better to have 3 or 4 fans running within the house, as the distribution of the gas must be as rapid as possible. If the fans were directed upward, the concentration of gas would be high at the top of the house and a good deal lower along the floor, requiring from 15 to 25 minutes for uniform distribution. With the fans placed at a height of from 5 to 8 feet from the floor and the air current directed straight down, however, the gas rising from the floor is forced downward again, circulating through the lower beds and rising in the side aisles. In this case, also, uniform distribution of gas requires from 15 to 25 minutes, but in the meantime the higher concentration remains at the floor level, where it does the most good. In the case of sodium cyanide and acid, a fan should be placed directly above each generator at a height of about 8 feet. Figure 1 shows a comparison of typical concentrations secured at the top, bottom, and middle of mushroom houses, (*A*) with fans directed upward, and (*B*) with fans directed downward. It will be observed that the concentration becomes uniform in about 25 minutes in both cases, by which time it has dropped considerably. It will be seen further that the concentrations are reversed by the fans, the downwardly directed fans keeping the highest concentrations of gas at the floor.

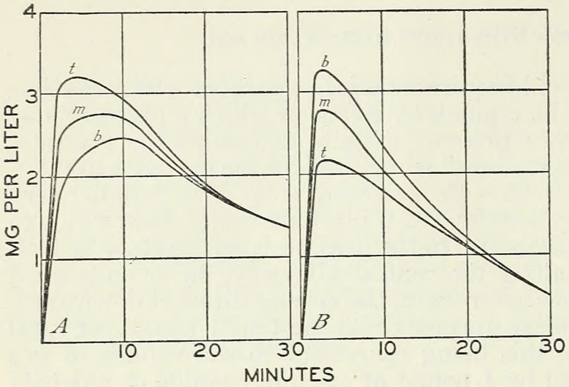

FIGURE 1.—Typical curves showing the concentration of hydrocyanic acid gas during fumigation of mushroom houses: *A*, Fans directed upward; *B*, fans directed downward; *t*, *m*, and *b* indicate concentrations at top, middle, and bottom of the house, respectively.

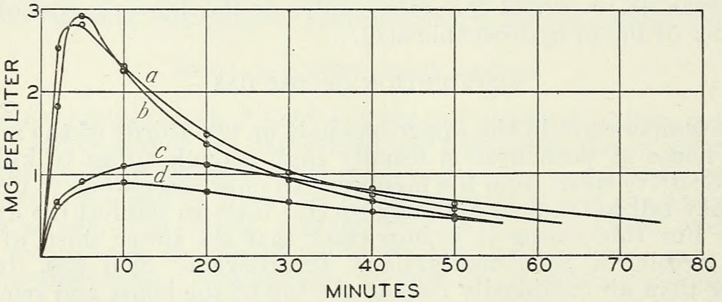

FIGURE 2.—Average concentrations of fumigant obtained in mushroom houses from the use of different sources of hydrocyanic acid gas: *a*, Gas generated with sodium cyanide and acid; *b*, gas from liberation of liquid hydrocyanic acid; *c*, gas generated from calcium cyanide in powder form; *d*, gas generated from granular calcium cyanide.

In comparing the concentrations of gas obtained from the various types of cyanide, the concentrations about half way between floor and ceiling of the house, along the center walk about 12 feet from the door, were used. At this point the concentration usually represents a fair average between that at the top and bottom of the house, regardless of the material used and the position and direction of the fans (fig. 2).

The concentration curves shown in figure 2 represent the averages of all those secured in fumigating commercial mushroom houses in the mushroom-growing district of Pennsylvania with approximately equivalent dosages of the three materials. Mean concentrations were calculated only to the point where the concentration of gas dropped to 0.4 mg per liter, because beyond that point there is little fumigating effect in a mushroom house.

By taking from the curves of figure 2 the concentrations indicated at the peak and obtaining the mean from the area below the curve as found by a planimeter, the figures given in table 1 are obtained.

TABLE 1.—*Maximum and mean concentrations of hydrocyanic acid gas at 5-minute intervals during fumigation of mushroom houses by different methods of gas generation*

[Averages from a number of commercial houses in eastern Pennsylvania]

Method of generation of gas	Maximum concentration	Mean concentration
	Mg per liter	*Mg per liter*
Pot method	2.81	1.20
Liquid from tank	2.93	1.23
Calcium cyanide (powder)	1.15	.80
Calcium cyanide (granular)	.89	.65

Granular calcium cyanide has been by far the most popular fumigant for mushroom houses at peak heat for the last few years. It is easily handled and not excessively dangerous. The highest peak concentration secured in any house was 1.88 mg per liter, while in several fumigations the peaks were below 0.5 mg per liter. Of those reaching a peak concentration above 0.8 mg per liter, most dropped below 0.4 mg per liter within 60 minutes. In most cases the peak concentration is reached within 15 minutes. The fact that leakage is almost as important a factor as absorption in lowering the concentration is shown by one fumigation with this material in an exceptionally tight house, in which the concentration reached 1.62 mg per liter and required over 100 minutes to drop to 0.4 mg per liter. Figure 2, *d* shows the average curve secured with this material. The concentration dropped to 0.4 mg per liter in 56 minutes.

Calcium cyanide in powdered form is more bulky than the granular form and is somewhat more difficult to handle. As a rule, the peak concentration is somewhat higher than that obtained with the granular form, and is usually reached in a shorter time. The average curve obtained with it is shown in figure 2, *c*. Seventy-five minutes was required for the concentration to drop to 0.4 mg per liter.

The average curve with sodium cyanide and acid is shown in figure 2, *a*. In these cases 63 minutes was the average time required for the concentration to drop to 0.4 mg per liter. As a rule, the peak concentration is reached within 3 minutes, the generation of gas being very rapid.

Liquid hydrocyanic acid gave a high peak in about the same time as sodium cyanide. The slight delay in the rise to peak concentration shown in figure 2, *b*, is caused by the difficulty of measuring small quantities by weighing. It is necessary to run the liquid into the house rather slowly in order to weigh it accurately. Otherwise as much as one-fourth to one-half pound over the dosage required may run in before the valve can be closed. The concentration dropped to 0.4 mg per liter in an average of 56 minutes.

FUMIGATION TESTS ON INSECTS AND MITES

APPARATUS AND METHODS

The studies on the lethal effects of the fumigating gas were made at Arlington Farm, Va., where equipment for such purposes was available. The fumigation chamber used consists of a small metal-lined room containing 254 cubic feet. It is well insulated, and contains apparatus for temperature and humidity control. At temperatures up to 120° F. a relative humidity of around 90 percent can be maintained. A 16-inch electric fan gives rapid and uniform distribution of gas.

The insects used were the springtails *Lepidocyrtus lanuginosus* (Gmel.) and *Xenylla* sp., adults and larvae; and all stages of the mushroom fly *Sciara* sp. The mites were *Tyroglyphus lintneri* Osb. and *Histiostoma* sp., of which all stages were present. The insects and mites, upon finely divided mushroom spawn, were placed in metal boxes having the tops and bottoms of fine wire screen. As exact figures on the percentage of mortality were not desired, no more than an approximate count of the insects used was made. In each box there were 15 to 20 individuals of *L. lanuginosus;* 10 to 20 larvae, several pupae, and 10 to 50 eggs of *Sciara* sp.; 25 to 30 each of adults and larvae of *T. lintneri* and *Histiostoma* sp.; and several thousand hypopi of each of the last two genera. The boxes were placed in the chamber upon a support about 3 feet from the floor in such a way that the gas could circulate freely through them. The insects were removed when the concentration had dropped below 0.4 mg per liter.

In order to simulate as nearly as possible the actual conditions existing in a mushroom house, the boxes containing the insects and mites were placed in the chamber at 75° or 80° F., and the temperature slowly raised to 100° through a period of from 6 to 8 hours. It was held at 100° for from 7 to 9 hours and the gas then introduced.

A series of test fumigations was conducted in the fumigation chamber at 100° F. and 90 percent relative humidity, beginning with a dosage that produced a peak concentration of 1 mg of hydrocyanic acid gas per liter, and in succeeding tests increasing the dosage in small steps until a point was reached at which no insects survived. The exposure consisted of either a single dosage or two or more dosages applied at intervals of 15 minutes, the total quantity being the same whether applied at once or in smaller quantities at intervals. The approximate lethal point having thus been found, a series of tests was run at each of several concentrations immediately above and below this point to fix it more closely.

In any given series of duplicate tests, the concentrations (determined at intervals of 5 minutes) were averaged, and an average curve for the series constructed from these figures. Mean concentrations were determined from these curves by the use of a planimeter. The fumigations and the curves drawn from them were designated as " sublethal " in cases in which approximately 1 percent or fewer of the insects or mites survived. Lethal fumigations were those in the same series or the next higher in concentration in which no insects or mites survived. The insects were removed when the concentration had dropped to 0.4 mg per liter, and the area of the curves is measured to that point except in the case of figure 3, *d*, which is measured only to 0.8 mg per liter.

Sodium cyanide was used as the source of the fumigant because it was quickly handled and easy to control. Samples were taken, and the concentration of the gas was determined by the official modification of the Liebig method.[1]

RESULTS OBTAINED

Since the temperature at the floor of the average mushroom house is in the neighborhood of 100° F. at the time of peak heat, this temperature was used in the fumigation-chamber tests. For practical purposes the higher temperatures farther from the floor in the houses may be ignored as the insects that survive the heat there are killed by lower concentrations of gas than those at the comparatively cooler floor level. At 100° in the fumigation chamber the springtails and all stages of *Sciara* were killed by a mean concentration of cyanide gas of 0.81 mg per liter in an exposure of 40 minutes. Mites were little affected by these conditions, some having survived even an exposure of 90 minutes to a multiple fumigation remaining above 1.3 mg per liter, and with a mean of 1.73 mg per liter. An exposure of 35 minutes to a single fumigation reaching a maximum of 3.5 mg per liter, having a mean of 1.8 mg per liter and dropping to 0.4 mg per liter in 35 minutes, also gave survivals. Figure 3 shows composite curves for all fumigations made in the chamber at 100°, *a* and *b* being single fumigations and *c* and *d* representing double fumigations in which two-thirds of the charge was set off in the beginning of the fumigation and the other third 15 minutes after the first one.

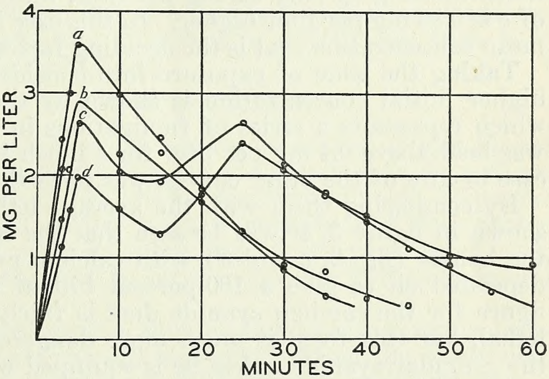

FIGURE 3.—Average concentrations obtained in the fumigation chamber divided into four groups representing (*a*) lethal concentrations obtained with single fumigations, (*b*) sublethal concentrations from single fumigations, (*c*) lethal concentrations from double fumigations, and (*d*) sublethal concentrations from double fumigations.

From these curves the figures in table 2 are obtained, using, as in the case of table 1, the mean concentration found by the readings of a planimeter.

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[1] ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. Ed. 3. 593 pp., illus. (p. 51.) 1930. The procedure is briefly described as follows: Liter samples drawn from the fumigation chamber by means of a siphon were bubbled through a solution of sodium carbonate containing potassium iodide, and this titrated with a 0.01 normal silver nitrate solution.

TABLE 2.—*Maximum and mean concentrations of hydrocyanic acid gas obtained in a fumigation chamber*

[Averages of a number of tests classified as lethal and sublethal]

Concentration and method	Maximum concentration	Mean concentration
	Mg per liter	*Mg per liter*
Lethal concentration, single fumigation, curve *a*	3.6	1.67
Sublethal concentration, single fumigation, curve *b*	2.9	1.56
Lethal concentration, double fumigation, curve *c*	2.6	1.65
Sublethal concentration, double fumigation, curve *d*	2.4	1.29

Omitting the consideration of time, a comparison of curves *a* and *b* shows that the higher maximum concentration is the deciding factor, the lengths of exposure being only 5½ minutes different and the mean concentrations differing by only 0.11 mg per liter. Comparison of curves *c* and *d* does not show this so clearly, the maximum concentrations differing by only 0.2 mg per liter, while the mean concentration of *c* is 0.36 mg per liter higher. In this case it is probably the greater mean concentration that is the deciding factor.

Taking the time of exposure into consideration, the value of the higher initial concentration is shown by the fact that the curve *d*, which represents a series of fumigations in which the concentration was held above 0.4 mg per liter for a much longer period than in the case of any of the other curves, was nevertheless sublethal.

By comparing them with the average lethal and sublethal curves shown in figure 3, it will be seen that the concentrations secured in the houses (fig. 2, *c* and *d*) with calcium cyanide are too low to be depended on to give a 100-percent kill of insects and mites. The figure for the calcium cyanide dust is fairly close to the theoretical lethal, but this form is much more dangerous to the operator than the granular cyanide unless he is equipped with a gas mask.

Liquid hydrocyanic acid gives a high peak of gas concentration in a very short time, as compared with calcium cyanide. It is easily handled by a trained operator, and as the gas is forced into the house from the outside there is a minimum of danger in its use. The main objections are that a pipe line must be used, and such a system, if temporary, is difficult to shift while the house is hot, or, if permanent, will be expensive; and also that the cylinders are bulky and heavy.

Sodium cyanide and acid give, in equivalent dosages, almost as high a concentration as liquid hydrocyanic acid, and produce the peak concentration within 5 minutes. It involves somewhat more trouble to measure out acid and weigh or count out sodium cyanide than simply to weigh out calcium cyanide, but it is not so difficult or unpleasant as installing a temporary pipe line for liquid hydrocyanic acid. Both acid and cyanide must be handled with extreme care to avoid unpleasant results. Rubber gloves are usually worn when handling either of these materials. From the standpoint of danger to the operator under mushroom-house conditions, sodium cyanide is less dangerous, if properly handled, than calcium cyanide, and very little if any more so than liquid hydrocyanic acid. The operator starts at the far end of the house and moves forward to the open door at the front end. He can see where he is going at all times, minimizing the possibility of stumbling over some obstacle. If very heavy or doubled paper bags are used for the cyanide, or if the operator moves rapidly, he is usually completely out of the house before the first generator commences to evolve gas. For greenhouse fumigation there has been used a rod with arms that permits the cyanide to be dumped into all generators simultaneously from outside the house. This would be inexpensive and its use would remove all hazard. Regulation of the dosage is very easy with sodium cyanide. In this connection, although the concentration secured with the dosage of one-half pound per 1,000 cubic feet of air space, or 8 pounds to the standard house of 16,000 cubic feet, seems high enough for the average house, an increase to 10 ounces per 1,000 cubic feet (or 10 pounds per standard house) would seem advisable, in order to give a generous margin of effectiveness.

From the standpoint of cost, calcium cyanide at the standard dosage of 1 pound per 1,000 cubic feet of air space and liquid hydrocyanic acid at the equivalent dosage come to the same figure ($4 at the present time) per house. Use of an equivalent dosage of sodium cyanide would bring down the total cost to a little less than half that figure ($1.98 at the present time).

SUMMARY AND CONCLUSIONS

In the fumigation of commercial mushroom houses, it was shown that when chemically equivalent dosages of calcium cyanide, sodium cyanide with acid (1–1½–2), and liquid hydrocyanic acid (1 pound calcium cyanide, one-half pound sodium cyanide and one-quarter pound hydrocyanic acid per 1,000 cubic feet of air space) were used, the last two were much superior to calcium cyanide in the concentration of gas obtained.

Liquid hydrocyanic acid gave a slightly higher maximum concentration of gas than sodium cyanide and acid. From the standpoint of safety, if properly handled, there is little choice between the two.

The average results from tests made in a fumigating chamber show that mushroom insects and mites in a temperature brought from 75° or 80° to 100° F. in from 6 to 8 hours, held at 100° for from 7 to 9 hours, and then fumigated with hydrocyanic acid gas, were all killed by a concentration that reached a maximum of 3.6 mg per liter, had a mean of 1.67 mg per liter, and required 44 minutes to drop to 0.4 mg per liter. An average of the curves drawn from single fumigations made in the fumigation chamber which produced slightly under 100 percent kill shows a maximum concentration of 2.9 and a mean concentration of 1.56 mg per liter, with a drop to 0.4 mg per liter in 38½ minutes.

Multiple or " interval " fumigations were found to be less effective than those in which the same total amount of material was used in one dosage, giving a higher maximum concentration but a shorter exposure.

The cost of fumigation per unit with sodium cyanide is about one-half that with either of the other two materials. It is recommended that on account of the leakage encountered in many of the houses the dosage for the average mushroom house be increased to 10 ounces of sodium cyanide or to 5 ounces of the liquid hydrocyanic acid per 1,000 cubic feet of air space.

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